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Tests of Aircraft Navigation For Small Area Mapping Using Minimum Local Aids To Navigation

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13. ABSTRACT

A U. S. Coast Guard HC-130B aircraft was flown on a parallel track pattern while within range of a high accuracy tracking radar, and the navigational performance of the aircraft while using only certain specified aids was observed. The aids used were LF and UHF radiobeacons, the aircraft's doppler radar, a transponder for the aircraft's search radar, and an inertial guidance system.

ABSTRACT

TESTS OF AIRCRAFT NAVIGATION FOR SMALL AREA MAPPING USING MINIMUM LOCAL AIDS TO NAVIGATION

A need exists for a means or technique for navigating aircraft accurately for small area mapping surveys in remote areas where high accuracy aids to navigation are not available. Consequently, tests of aircraft navigation using several aids to navigation potentially suitable for use in remote areas were performed at the National Aviation Facilities Experimental Center. A U. S. Coast Guard HC-130B aircraft was flown on a parallel-track pattern while within range of a high accuracy tracking radar and the navigational performance of the aircraft while it was using only certain specified navigational aids was observed. The aids used included LF and UHF radio beacons, the aircraft's doppler radar, a ground-based transponder for the aircraft's search radar and an inertial guidance system

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FIGURE 1

TYPICAL SLAR MOSAIC

Mission #10, 15 March 1971, AIDJEX SITE
"BEST FIT", SLAR MOSAIC

Tests of Aircraft Navigation For Small Area Mapping Using Minimum Local Aids to Navigation

Introduction

One of the programs of the Applied Sciences Division of the Office of Research and Development is a comprehensive investigation of techniques and sensors for airborne sea ice reconnaissance. In this program various sensors are fitted to an aircraft, which is then flown over a test site located on sea ice. The test site is frequently in the vicinity of a very small camp or surface party, the purpose of which is to obtain "ground truth", or actual knowledge of the ice conditions. This information is later compared to the data obtained by the aircraft sensors. In many areas of the Arctic there normally are no short range electronic aids to navigation (hereafter referred to as "Aids") that are required for accurate small area mapping, and it is a complex and expensive proposition to establish them to support an investigation of this type. Knowledge of the accuracy with which the aircraft can be navigated when guided by various Aids or combinations of Aids would allow a trade-off to be made between the navigational accuracy desired and the expense and difficulty of establishing an Aid or Aids on the Arctic ice. The purpose of the flight tests reported herein was to provide the data on which this trade-off could be based.

An example of the utility of accurate local area navigation for aerial mapping is shown in Figure 1. This Figure is a portion of a radar mosaic of an area in the Beaufort Sea about 600 miles northeast of Fairbanks, Alaska. The mosiac was prepared by fitting together the best portions of data obtained from several passes over the area. It can be readily seen that the more nearly parallel and evenly spaced the aircraft's track, the more efficiently large areas can be mosiaced.

It is recognized that the tests reported herein are definitely not exhaustive in their completeness. However, it is felt that these tests, which were oriented toward a particular navigational situation rather than a specific item of equipment, will help to fill a gap in the available literature.

It might be pointed out that the data obtained from these experiments is directly applicable to open ocean searches, because the navigation problem there is virtually the same as for Arctic ice reconnaissance.

Test Objectives

The primary objective of this experiment was to determine which of the prescribed Aids or combinations of Aids enables the aircraft to traverse the prescribed trackline with the least deviation. That is, the primary legs were to be straight, parallel and evenly spaced with a 5 n.m. separation. The position or orientation of the trackline with respect to datum was of secondary importance.

A secondary objective was to roughly quantify the navigational accuracy feasible when only the particular Aid being tested was available to the aircraft.

Test Plan

The situation that this experiment was designed to help improve may be summarized as follows: The aircraft takes off from a Base and flies at high altitudes for 1-2 hours towards a certain Point in the Arctic Ocean. A radiobeacon has previously been established at the Point. When near the Point, the aircraft uses its Automatic Radio-direction Finder (ADF) to home on the beacon and arrive "overhead". Then a parallel track pattern, centered on the beacon is flown using the beacon and such other Aids as are available.

For these tests this situation was partially simulated. The high altitude flight enroute to the Point was dispensed with and the test locale was near Atlantic City, N. J. The simulated "Point" was marked with radiobeacons established prior to the tests. The aircraft was directed to repeatedly fly along a specified parallel track pattern using only certain, specified Aids, under navigational conditions that duplicated as nearly as feasible actual Arctic conditions. The Aids examined included:

a) LF radiobeacon located at the Point
b) UHF radiobeacon located at the Point
c) Aircraft's doppler radar/computer system
d) X-band radar transponder located at the Point
e) Inertial Navigation System

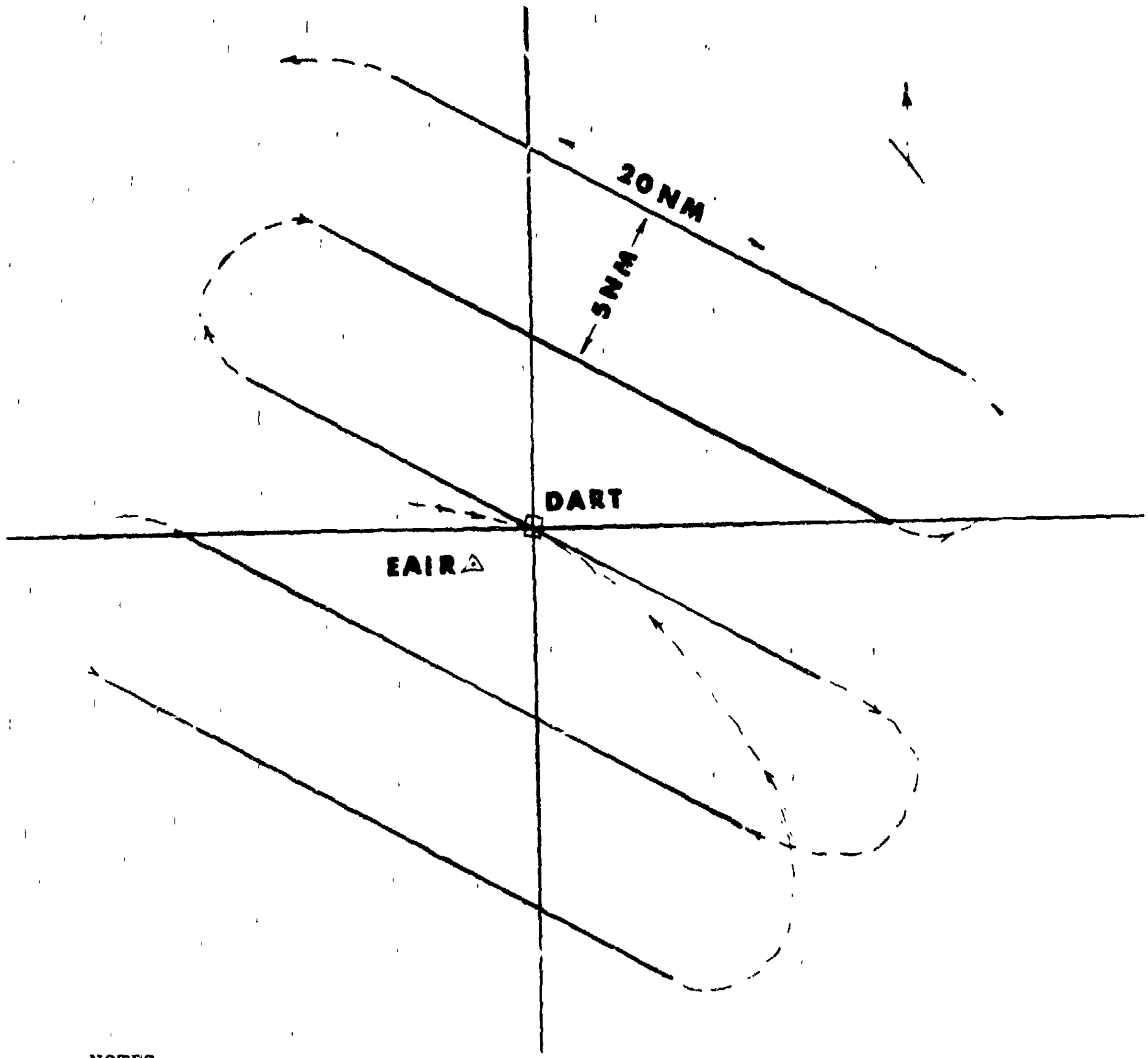
During the flight the aircraft was tracked by a high-accuracy ground radar to establish the accuracy with which the patterns were flown while using the various Aids.

Test Site

The tests were held at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey on 9 September 1971. NAFEC is equipped with a high accuracy tracking radar called an "Extended Area Instrumentation Radar" (EAIR), which is capable of determining the absolute position of an airborne target to within 20 yards out to a range of 50 nautical miles. To facilitate the use of this radar, a small transponder was fitted to the test aircraft. The primary advantage of using the transponder (rather than just relying on receiving echoes from the aircraft's hull) was that the tracking radar was able to track the test aircraft in spite of the disturbing presence of other aircraft.

FIGURE 2

INTENDED AIRCRAFT TRACK



NOTES:
(a) Location: National Aviation Facilities Experimental Center
(b) Track datum: D' ' Site, at NAFEC
(c) Tracking Radar. AFEC's Extended Area Instrumentation Radar (EAIR)
(d) Pattern was flown in two "halves", both originating at datum. Solid lines indicate that portion of the track where accurate navigation was desired and results were measured.

About 1-1/2 miles NE of the EAIR site is a cleared, paved area known as the DART site. The position of the DART site relative to the EAIR site is accurately known, so the UHF and LF radio beacons were established there to mark "datum".

Test Aircraft

The aircraft used for these tests was a U. S. Coast Guard HC-130B (CG-1346) with standard equipment except for two additional items. Standard navigational equipment of interest here includes magnetic compasses, several ADF's, VHF Omni-range/ Distance Measuring Equipment (VOR/DME), LORAN A/C, Doppler radar, and a weather-avoidance radar. The additional equipment consisted of an inertial navigation system, including a connection to the aircraft autopilot permitting the inertial system to provide left/right turn signals to the autopilot, and a C-band transponder to facilitate tracking by the EAIRadar. All of the navigation equipment on the aircraft appeared to be operating properly during the test except the Doppler Computer (AN/ASN-35). The normal aircrew was augmented to include a navigator for this experiment.

Test Performance

Prior to the tests the pilots were thoroughly briefed and were given the following instructions in writing:

(a) The aircraft is to fly the track shown in Figure 2.

(b) NAFEC will maintain a radar track of the aircraft, but will not provide navigational information to the aircraft.

(c) The aircraft's compass is to be in the free gyro mode, as for high latitude grid navigation.

(d) The autopilot is to be used to the maximum practical extent.

(e) The aircraft's ground speed is to be maintained between 150 and 300 knots on the 20 n.m. legs. The true air speed should be held constant at a value such that the ground speed will be within the above limits when the aircraft is on the upwind or downwind legs.

(f) The aircraft will not use VOR/DME, LORAN A or LORAN C, radiobeacons or radar, except as directed. The aircract is to make five flights over the track indicated in Figure 2, using a different aid (selected from the list below) each time.

(1) LF beacon located at datum.

(2) UHF beacon located at datum.

(3) Aircraft's doppler radar/computer system.

(4) X-band radar transponder located at datum.

(5) Inertial navigation system.

(g) When runs (1) and (2) above are being flown the aircraft is to be navigated solely by dead reckoning and ADF bearings.

(h) During run (4), the radar transponder data is to be used to up-date the doppler computer whenever the transponder appears within the arc of coverage of the aircraft's radar. Radar data on other points in the test area is not be be used.

The following are specific comments on each portion ("Run") of the test.

Run 1: It was originally intended that this run (see Figure 3) was to be flown using the LF radiobeacon as the aid; that is, the navigator was to obtain running fixes from lines of bearing to the beacon. In practice, however, the ADF indicator "hunted" too much, especially when the beacon was between 090 and 270 relative to the aircraft, so that the navigator could not use it with adequate accuracy. As a result, the second half (the NE half) of the track flown on this run was navigated with a combination of dead reckoning (D. R.), doppler drift meter and LF ADF. Unfortunately, the LF beacon was inadequately grounded and thus was not radiating a very strong signal (probably about 1/2 watt). It remains a possibility that a stronger signal might have resulted in a more stable LF ADF indicator reading, although the signal used was audible at all times.

Run 2: This run (see Figure 5) was intended to be similar to Run 1, except that a low power UHF beacon (AN/SRT-981) was to be used instead of the LF beacon. The beacon appeared to be working properly on this run, but the signal strength became completely unreadable at a distance of 8-10 miles (the aircraft altitude was about 8000 feet), and the indicator began hunting badly when the beacon direction was between 090 and 270 relative to the aircraft while at lesser ranges. So, again, this run was navigated by D. R. and doppler drift meter with occasional input from the ADF.

Run 3: The intention for this run (see Figure 7) was to use only the aircraft's doppler radar and computer, except the beacons could be used to bring the aircraft over datum. The doppler computer was discovered to be inoperative, however, so the navigator used the doppler radar instantaneous ground speed and drift data. The first portion of the second half of the run was marred by a misunderstanding between the flight crew and the test personnel.

Run 4: This run (see Figure 9) was to utilize range and bearing data from the aircraft's search radar interrogating a transponder located at datum. However, the transponder frequency adjustment proved to be extremely critical to adjust--at least, that was the apparent problem. As a result, the radar was not interrogating the transponder reliably enough for use for this experiment. The aircraft DR'd through 1/2 of the track while attempts were made to adjust the equipment and, interestingly, the wind had died out during much of this period. As a result, this run was the best of the day.

Run 5: The inertial guidance system was used for this run (see Figure 11), with the end points of each leg entered into the system computer as waypoints. The latitude and longitude of the end points were determined incorrectly, resulting in a track that barely resembled that which was desired. Also, the system had been started and aligned about 4-1/2 hours earlier, so a substantial amount of drift had accumulated, compared to the track data actually entered into the machine. Note, though, that the tracks flown were quite parallel to those programmed.

Run 6: This run, which not originally planned, was added on when the programming error in Run 5 was discovered. The procedure was as follows: After Run 5 was completed, but before the beginning of Run 6, the aircraft was guided by the tracking radar and test personnel to each of the ten trackline end points. The aircrew was then given a "mark" when over each point, and the inertial system was queried as to the current "position". Of course, the individual position data were arbitrary, reflecting the system drift. However, these values, relative to each other, were consistent with the desired track, because the short term accuracy of inertial navigation systems is high. In this manner the ten "positions" were obtained and entered into the inertial system's computer, and Run 6 was then flown. The aircraft track differed slightly for Run 5 and 6 from that used earlier, in that for these runs the aircraft started at an extreme end point and flew the entire trackline, rather than starting over datum and flying 1/2 of the track, then returning to datum to originate the second half of the track, as was done for the earlier runs. This later procedure was felt to improve the navigational performance when the ADF, etc. was in use, but was superfluous with the inertial system. Several factors which would tend to limit the performance of the inertial system. Several factors which would tend to limit the performance of the inertial navigation system in Run 6 were, first, the unavoidable errors associated with the human delays between the radar operator deciding to say, "mark", and the pushing of the button on the aircraft, and second, the fact that the system computer output display is limited to the nearest 0.1 n.m. Note that the errors on legs 2, 3 and 4 of Run 6 are of this order of magnitude. The large error on le 5 appears to be due either to a failure in the inertial system or to an error in entering the waypoints.

Data Collection and Reduction

The aircraft position data for this experiment was plotted in real time from the radar data by an X-Y plotter at a scale of 1.0 inch = 1.0 nautical mile. This equipment enabled the test personnel to observe and modify the experiment as it progressed. Figures 3, 5, 9, 11 and 13 are photographic reproductions (at reduced scale) of the X-Y plotter data. Some data was also recorded directly on magnetic tape for later comparison with the X-Y plotter data. The above mentioned figures have been edited a little bit to remove extraneous turns and maneuvers. Also, portions of several runs are shown with dotted lines. During these periods the radar was not operating properly, so the trackline shown is an estimate.

The data reduction consisted primarily preparing cross-track or radial error histograms for the six runs. The reader is cautioned to note the captions when comparing the several histograms in this report. The sampling width and type of error presented are varied and have a substantial affect on the data.

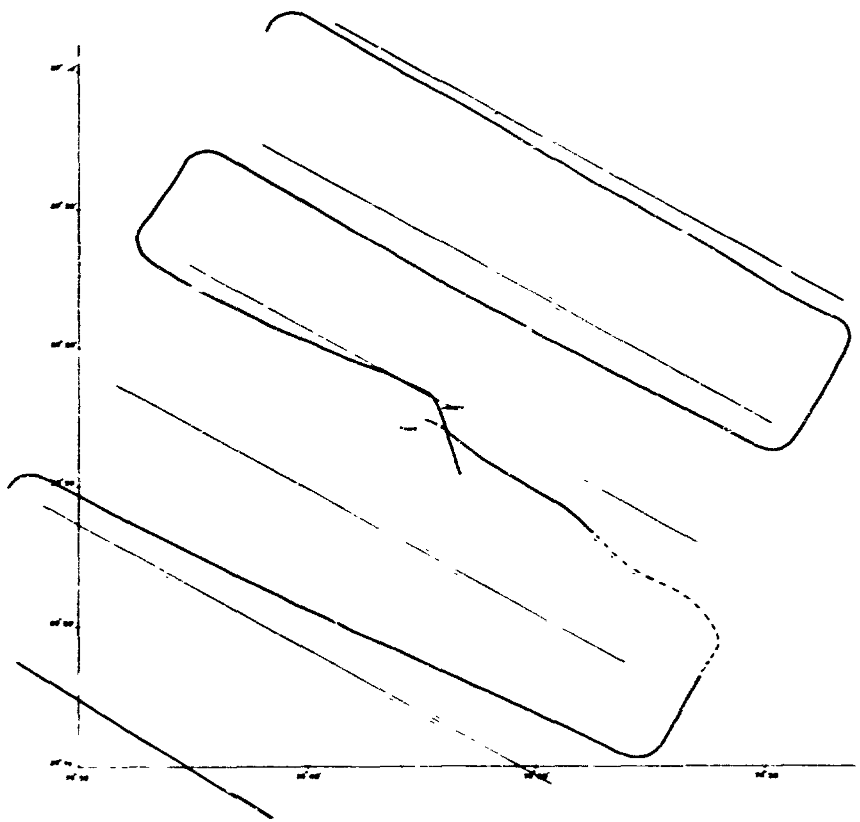
To provide a crude yardstick against which to judge the tracks actually flown, a "run" was synthesized using several simplifying assumptions. The "track" for this run appears in Figure 15, and its histogram in Figure 16. The important thing to note is that the errors were arbitrarily limited by how far the aircraft was "flown". It's also interesting to note that all of the legs that were "flown" in the same direction were quite parallel--this might be useful in a situation where the aircraft had no Aids at all.

Finally, Figure 17 was prepared in order to compare the general order of magnitude of the radial errors experienced with LORAN-A, TACAN and inertial navigation systems. Its only valid message is that, depending on the circumstances and the usage, inertial navigation systems may not be as "good" as LORAN or TACAN.

Results and Conclusions

The inertial guidance system demonstrated the best performance in a realistic situation, that is, with some wind present. This, of course was expected. The UHF DF does not appear to be too useful for aiding in navigating parallel track flight lines, although the LF DF may be of use when a stronger beacon is available. The radar transponder equipment did not work well enough for the technique of using it to be evaluated. Those portions of the aircraft's doppler radar system that were operative seemed to work well. Runs 1 and 2 were very good; however, Run 3, during which equipment processed doppler data, rather than instantaneous (that is, navigator-processed) data was used, has a relatively poor error distribution.

Figure 3



Reproduction of Rad.. Plot, Run 1

FIGURE 4

CROSS-TRACK ERROR HISTOGRAM

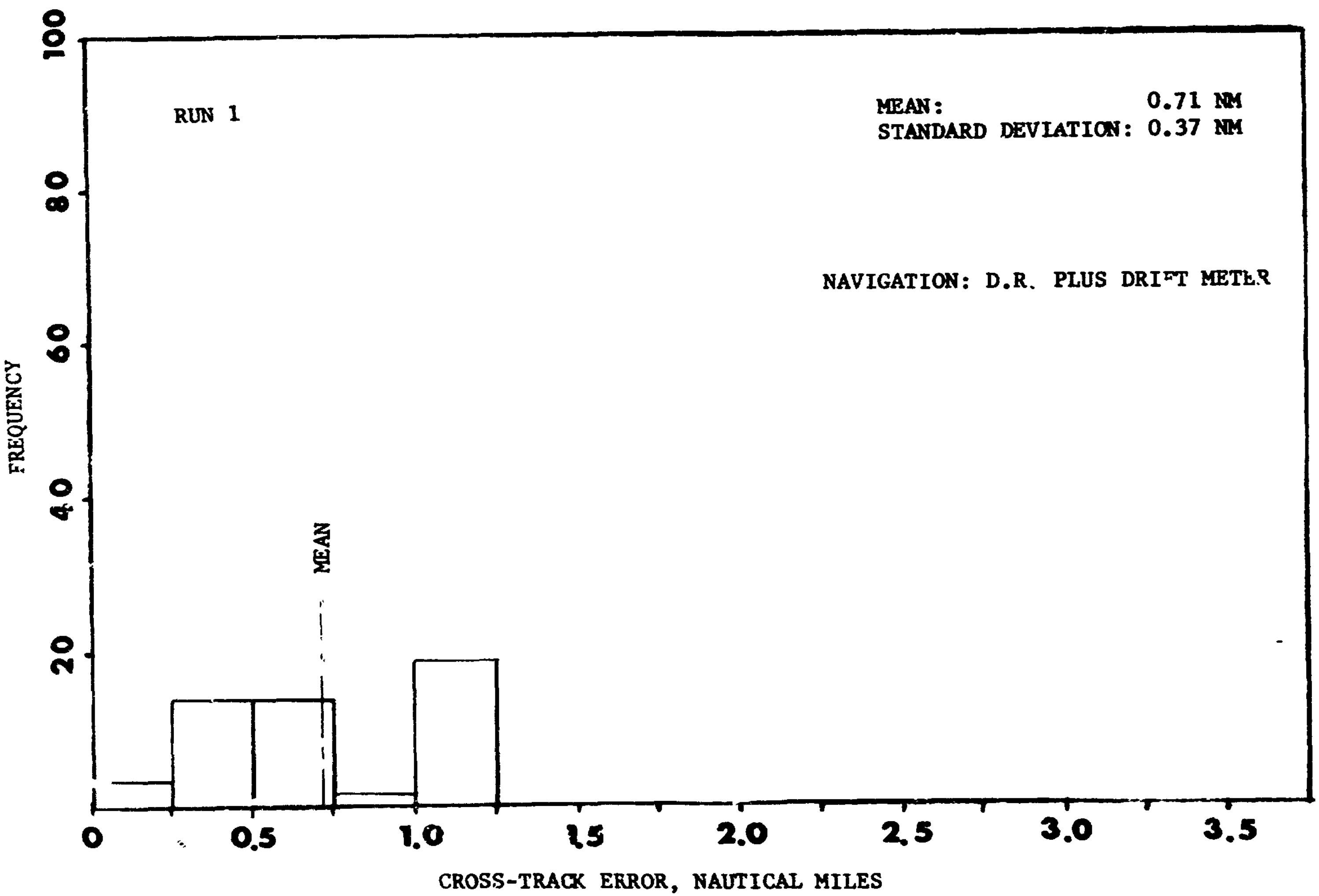
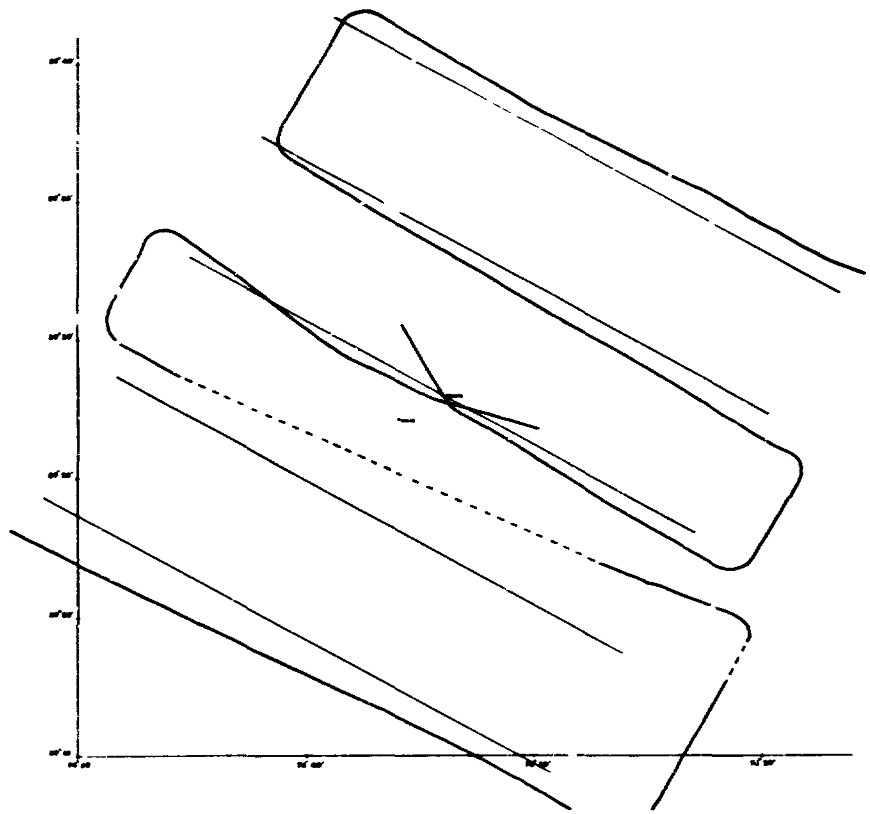


Figure 5



Reproduction of Radar Plot, Run 2

FIGURE 6

CROSS-TRACK ERROR HISTOGRAM

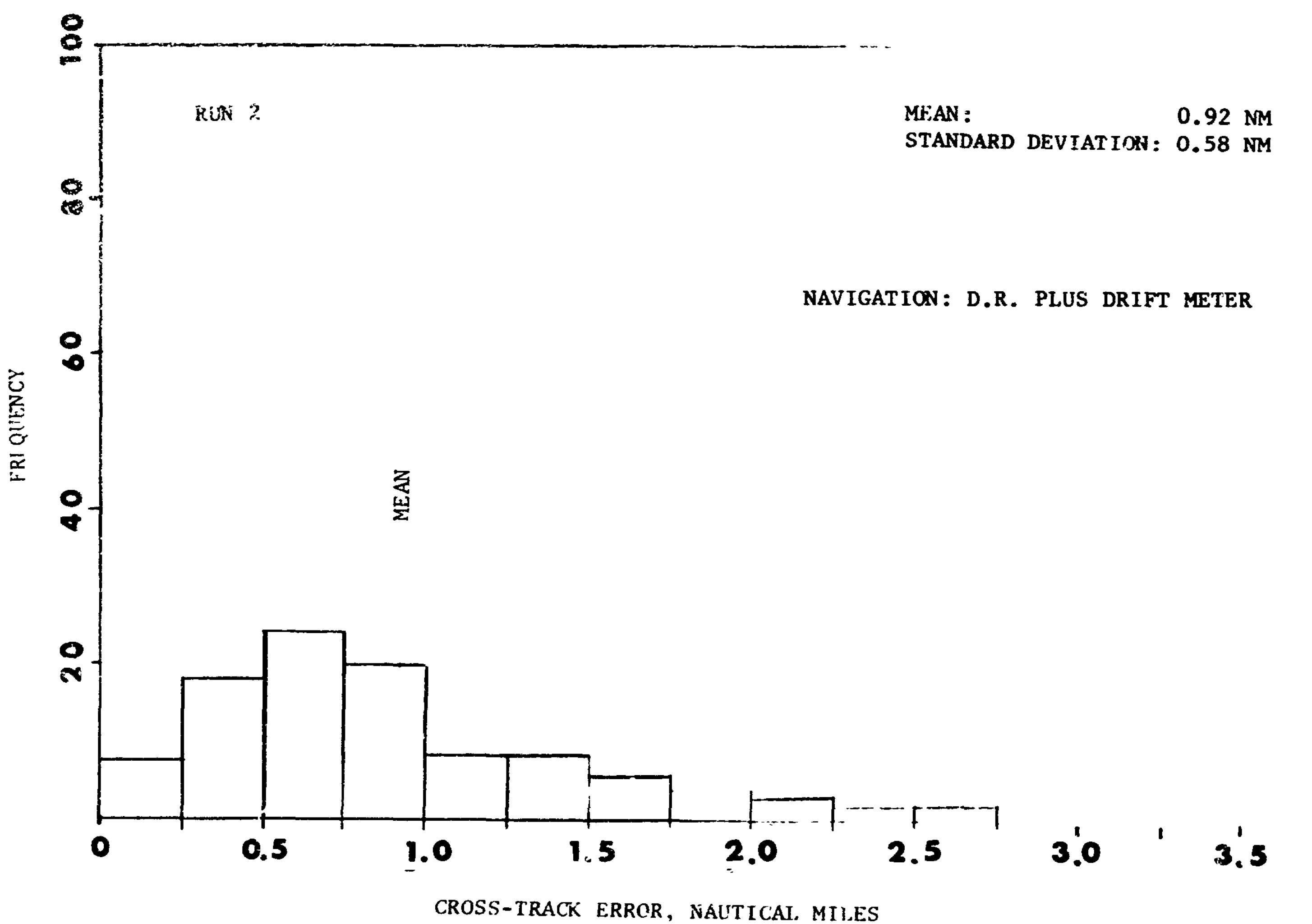
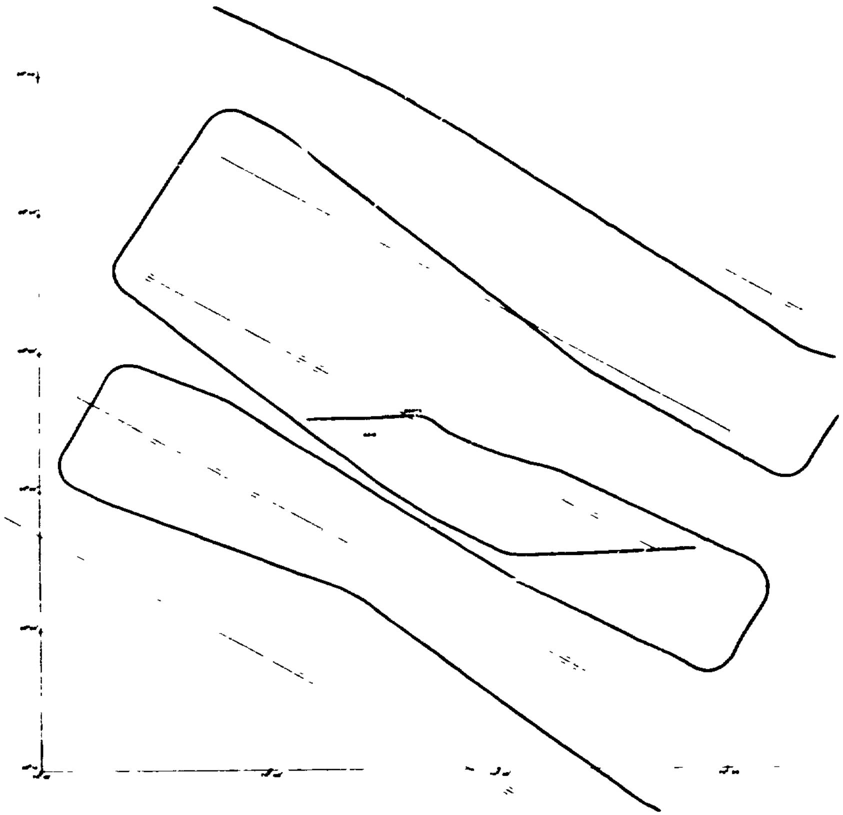


Figure 7



Reproduction of Radar Plot, Run 3

FIGURE 8

CROSS-TRACK ERROR HISTOGRAM

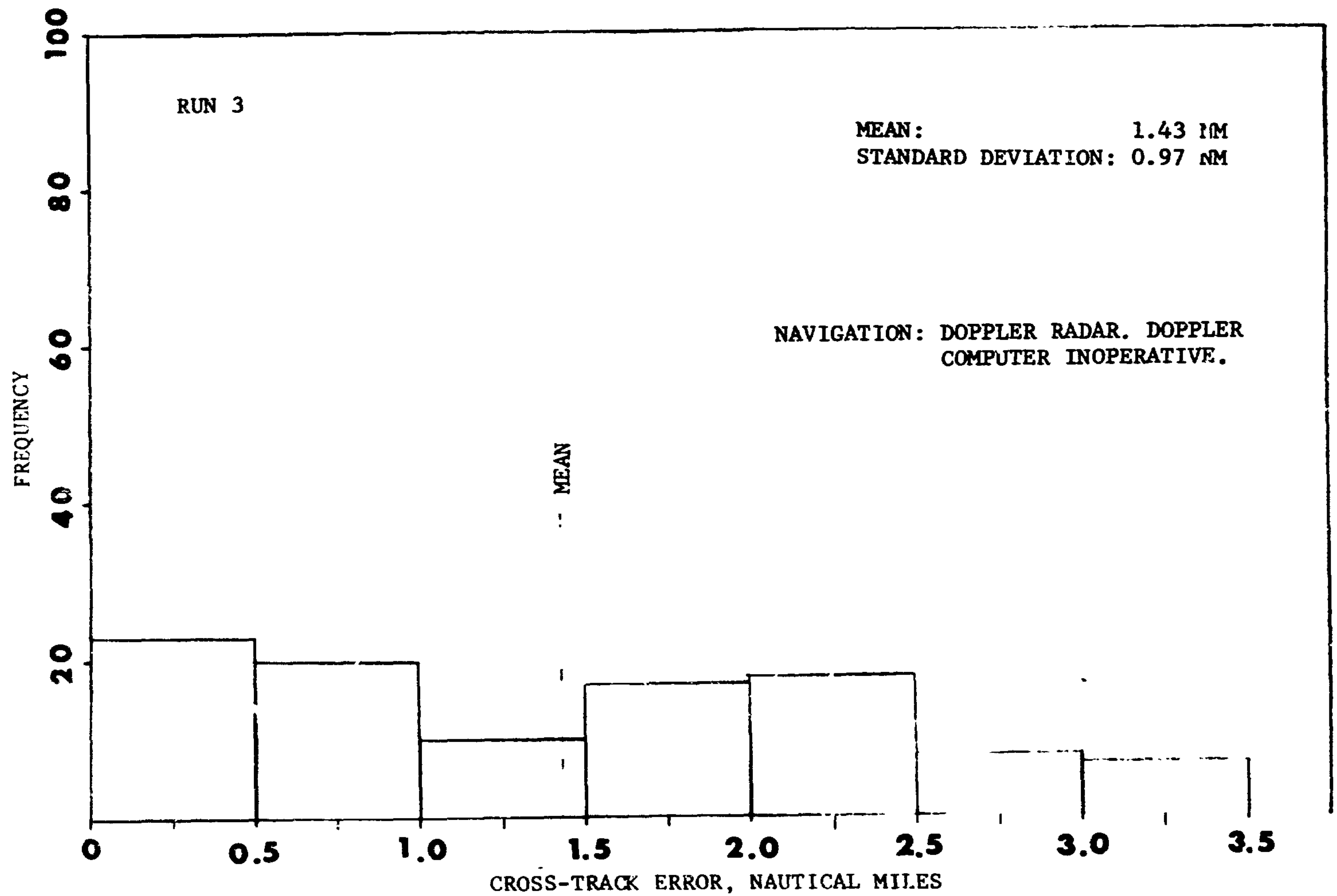
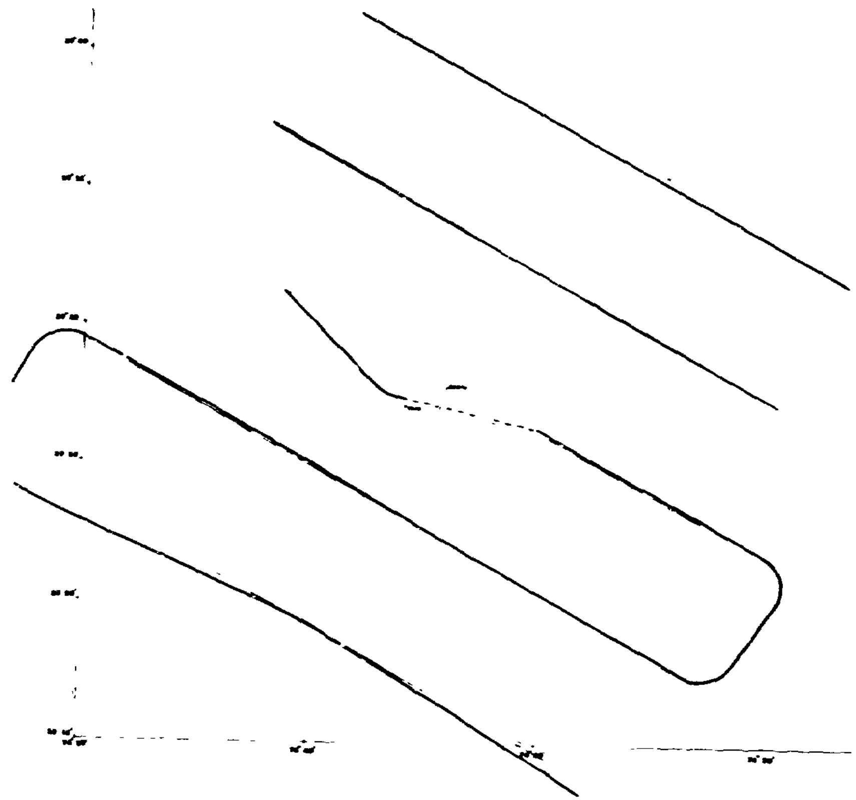


Figure 9



Reproduction of Radar Plot, Run 4

FIGURE 10

CROSS-TRACK ERROR HISTOGRAM

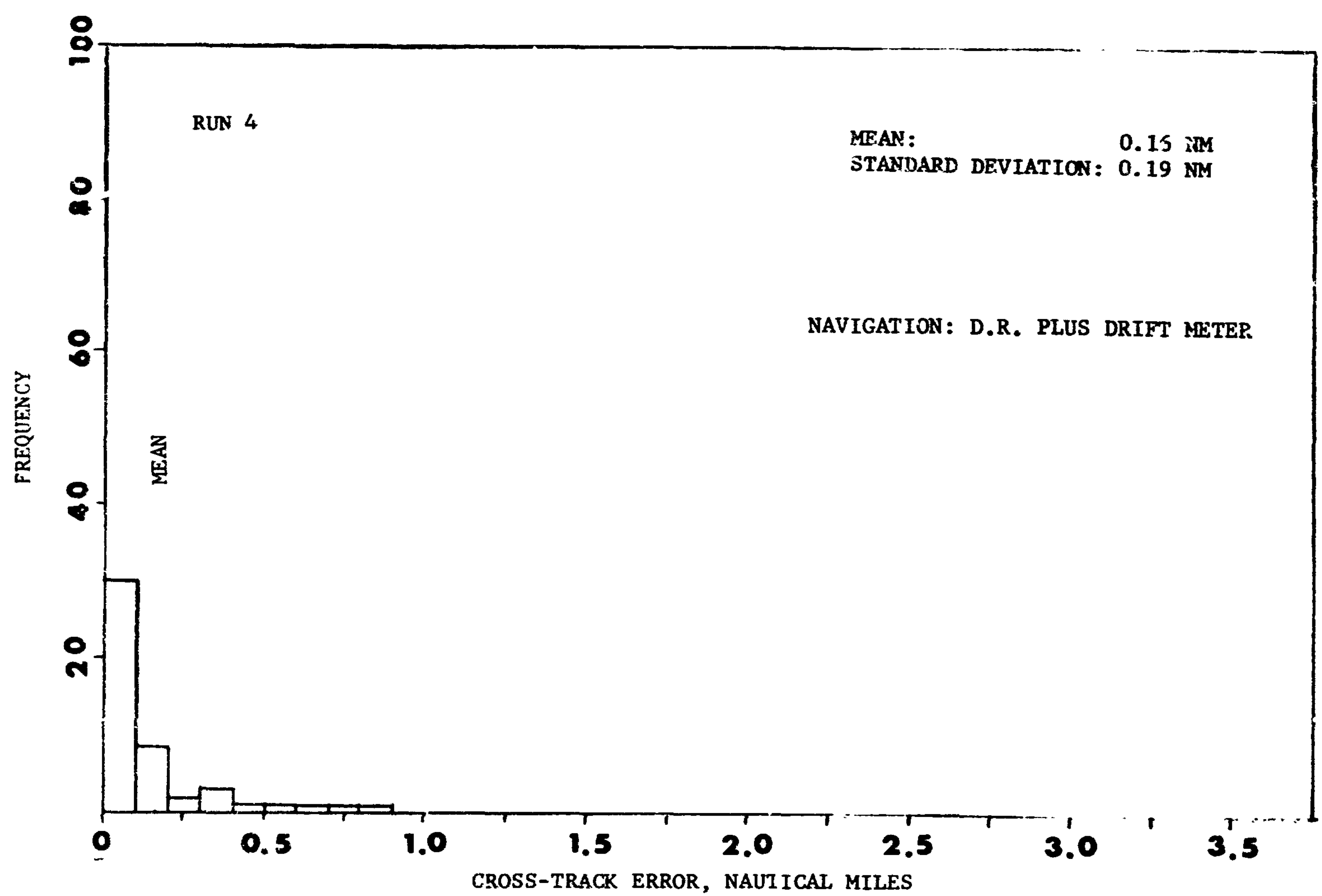
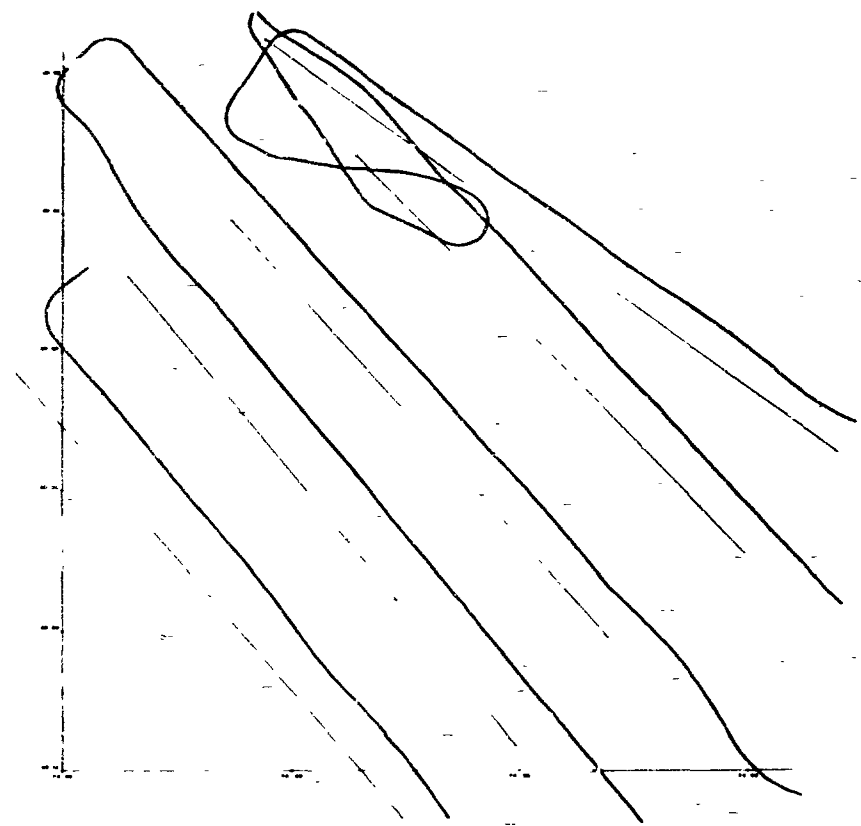


Figure 11



Reproduction of Radar Plot, Run 5

FIGURE 12

RADIAL ERROR HISTOGRAM

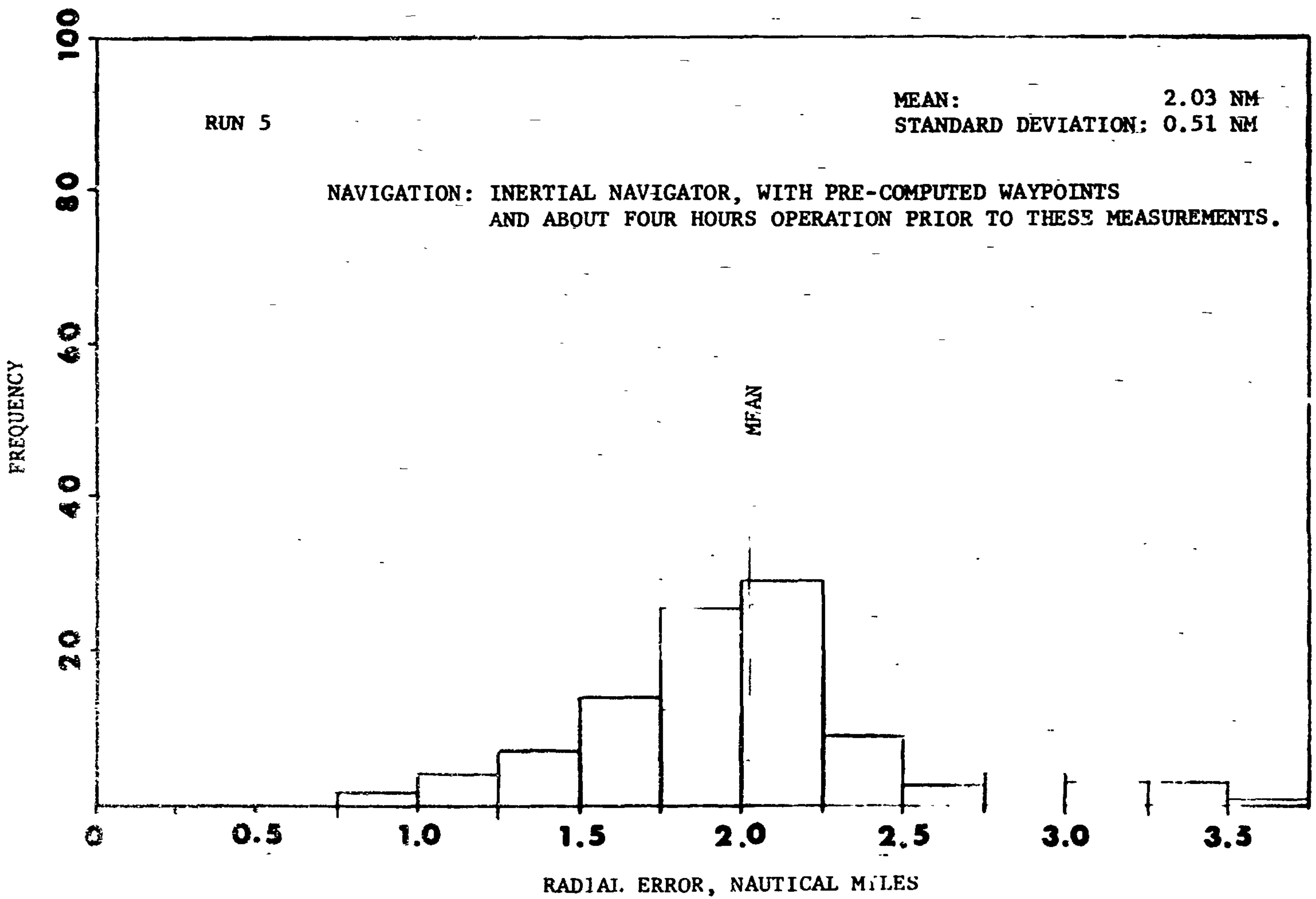
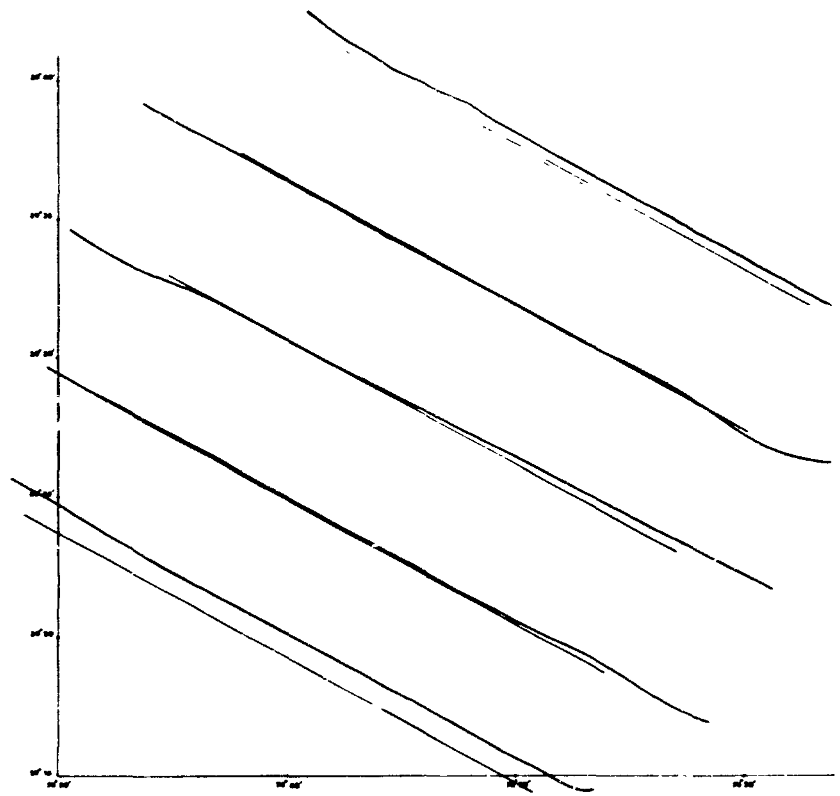


Figure 13



Reproduction of Radar Plot, Run 6

FIGURE 14

CROSS-TRACK ERROR HISTOGRAM

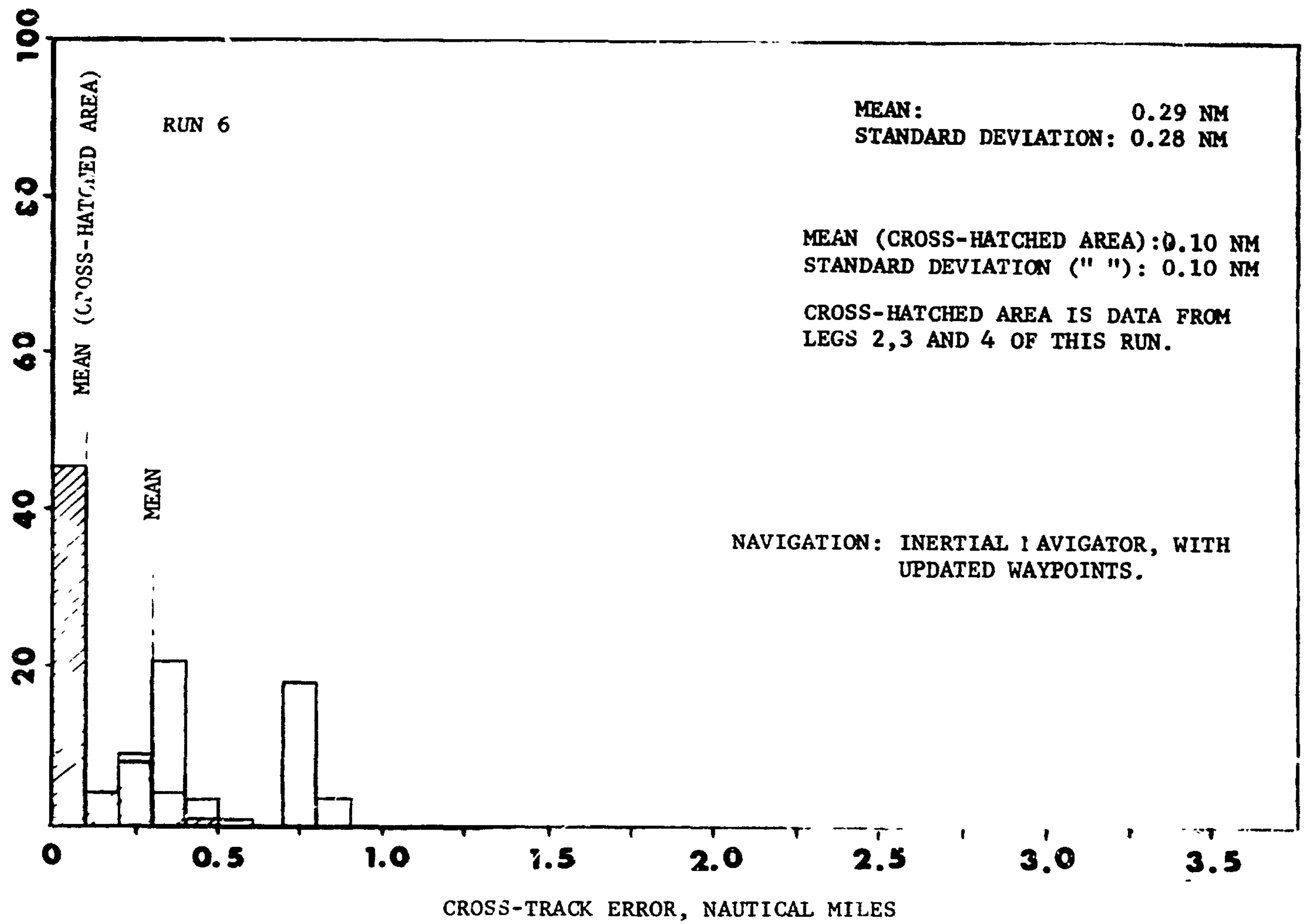
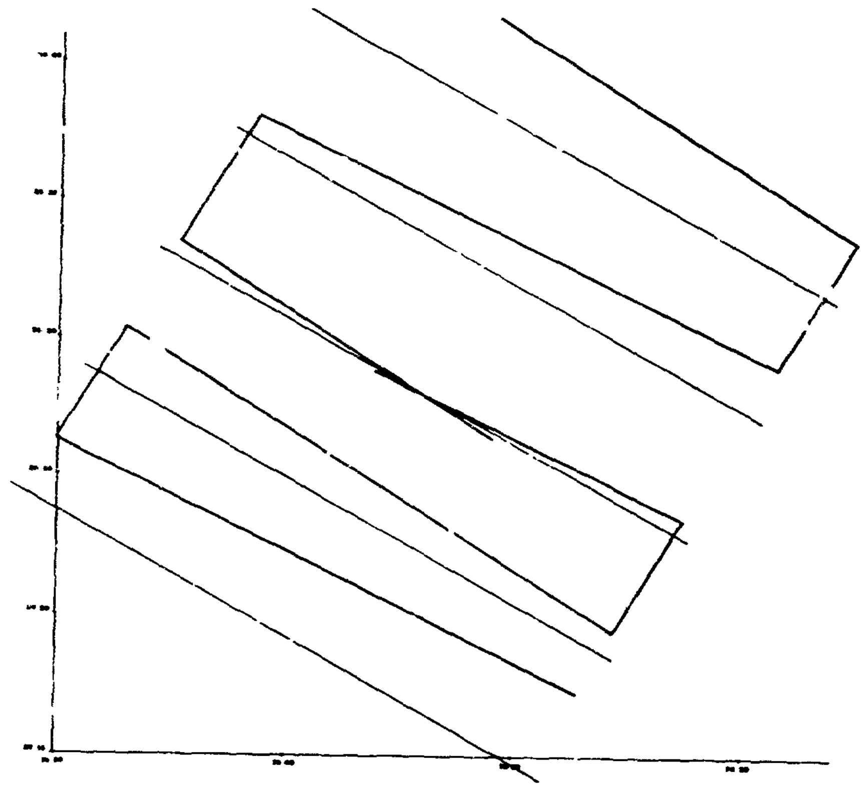


Figure 15



Plot, Synthetic Run

FIGURE 16

CROSS-TRACK ERROR HISTOGRAM

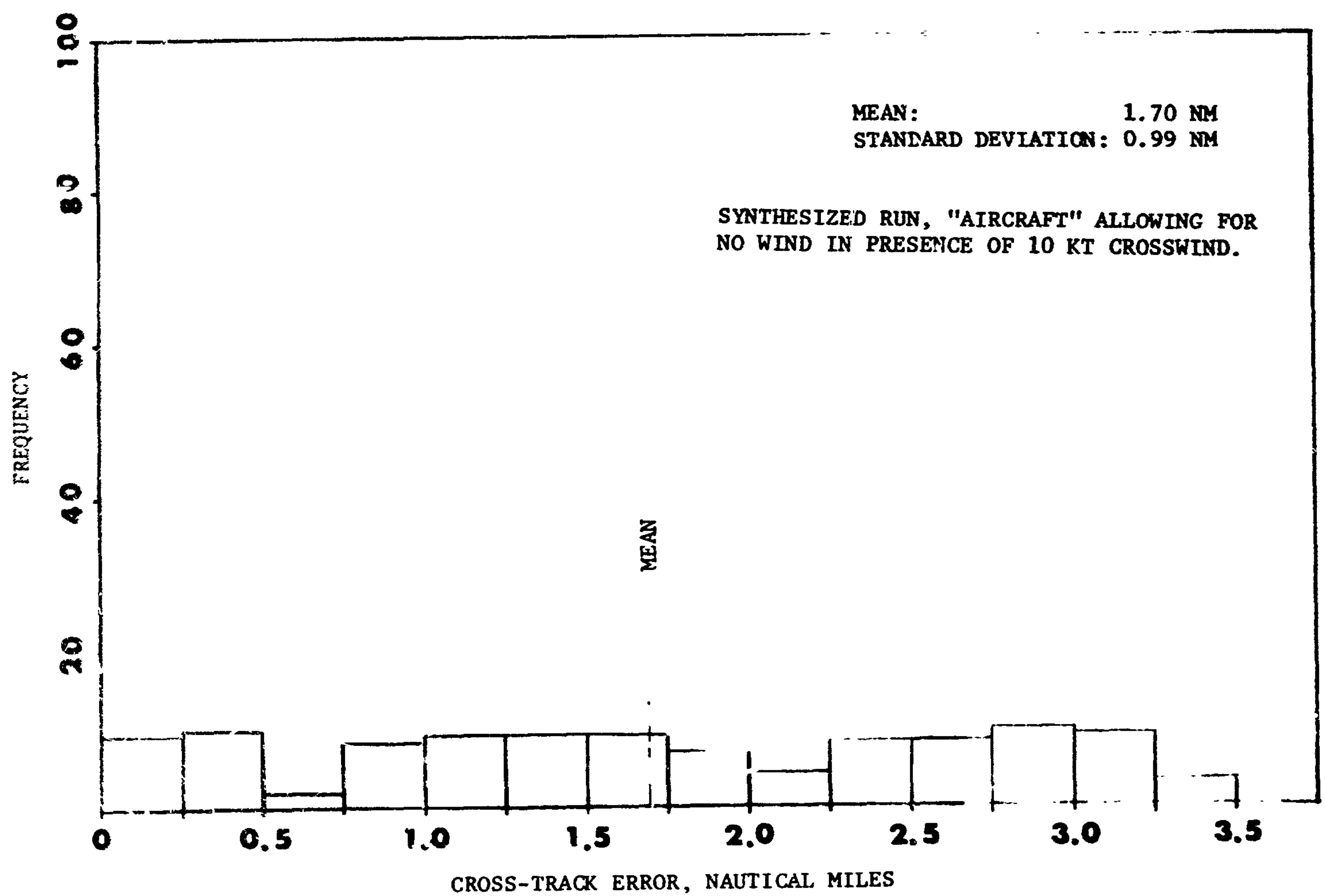


FIGURE 17

RADIAL ERROR HISTOGRAM

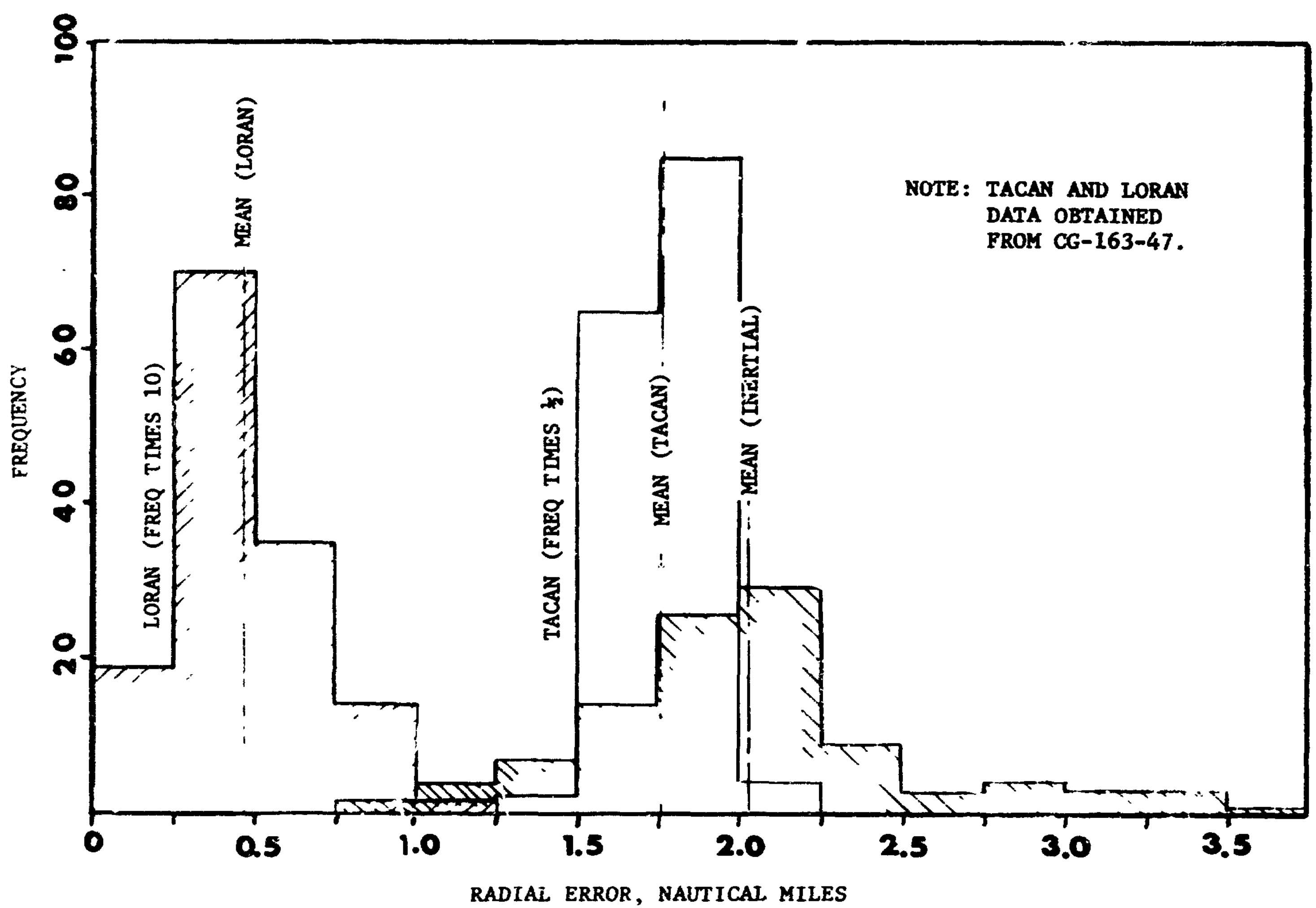
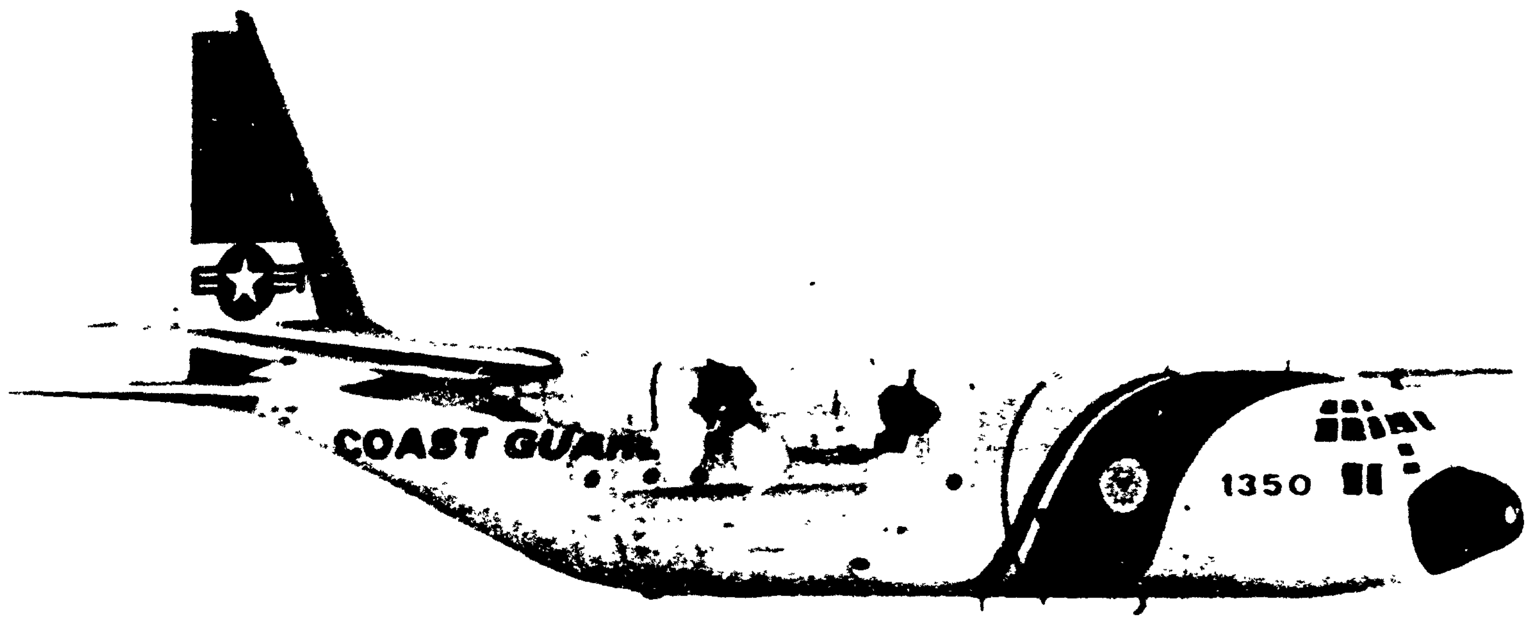


Figure 18



A Typical U.S. Coast Guard C-130

Figure 19

Inertial Navigation System as Temporarily Installed on Cargo Deck

Figure 20

Control Unit, Inertial Navigation System

Figure 21

Temporary Installation of Control Unit
At Navigator's Station

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